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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Program Manager: Dr. Charles Lee, (703) 696-7779, charles.lee@afosr.af.mil Air Force Office of Scientific Research 875 N. Randolph Street Rm 3112 Arlington, VA 22203 Susan L. Papa-Provost (703) 696-7296	**10. SPONSOR/MONITOR'S ACRONYM(S)**
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12. DISTRIBUTION/AVAILABILITY STATEMENT

Unlimited —A

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The goals of this program were to develop optical coatings that can resist or circumvent the detrimental effects of thermal gradients. New thin film materials were investigated and optomechanical design techniques were developed. Over the three years of the program, we have made major progress on three main thrusts. These are: 1) encapsulation techniques to stabilize the optical and mechanical properties of porous, reactive, or unstable thin films, 2) optomechanical design to create optical coatings with specified thermal and mechanical deformation, 3) negative thermal expansion (NTE) films that are stable with changing atmospheres. In addition we have preliminary results regarding two additional areas of inquiry that could have great impact on the coatings for high power lasers. These are: 4) infrared signatures to predict the onset of laser damage to optical coatings, and 5) atomic layer deposition for highly conformal coatings for high power beam combining.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	U	31	Joseph Talghader
					19b. TELEPHONE NUMBER *(Include area code)* (612) 625-4524

1. Cover Sheet

Performance Report

to the

Air Force Office of Scientific Research

and Joint Technology Office

Program title: Optomechanical Coatings for High Power Mirrors and Adaptive Optics

Principal Investigator: Joseph Talghader
Electrical and Computer Engineering
4-174 EE/CS Bldg.
200 Union St. SE
Minneapolis, MN 55455
(612) 625-4524
joey@ece.umn.edu

Institution: University of Minnesota - Twin Cities
Sponsored Projects Office
450 McNamara Alumni Center
Minneapolis, MN 55455-2070

Agreement number: FA9550-05-1-0399

Performance period: July 1, 2005 to September 1, 2005

2. Objectives

No change.

3. Status of Effort (First 2 months of program)

The program began on July 1 and, although it is only 2 months old, it is progressing well. The technical aspects of our recent work will be covered in more detail in the next section. The primary goals of the program are:

1) Discover the physics behind negative expansion in thin films: Work toward this goal is initially in the areas of film characterization and thus obtaining access and training in materials characterization equipment is of critical importance. We have already performed thermal expansion testing on negative thermal expansion (NTE) films and tested them using X-ray reflectometry and X-ray photoelectron spectroscopy. We are collaborating with Seagate Technologies to measure thermal expansion under vacuum to determine the effect of water vapor, if any. We are also attempting to develop this capability at the University of Minnesota. We are also collaborating with Argonne National Labs to test our films under extended X-ray absorption fine-structure spectroscopy (EXAFS), which should give us information about local bonding. Further, we are working with the University of Nebraska to gain access to their IR ellipsometry system, which may help us understand atomic vibration characteristics.

2) Develop new thermal expansion thin films: The first film that we have tested in regard to this topic is SiO2 and we have already found that SiO2 appears to have a strong negative thermal expansion when evaporated under the right conditions. More on these results are in the next section.

3) Incorporate these films into mechanically optimized high-power optical coatings: Progress on this topic was primarily slated to be performed with thin films on silicon and quartz substrates. However, our recent interaction with John Starkovich at Northrop Grumman may give us the capability to test polymer membranes for lightweight mirrors as well. We expect to test two NTE films on Kapton very soon.

4. Accomplishments/New Findings

A potentially critical new finding of the first two months of the program is that SiO_2 thin films take on a strong NTE when evaporated under certain conditions. At the moment, the critical conditions have not been isolated but have been found to be widely available within standard evaporation procedures. The films are consistently and strongly NTE even when annealed to 750°C, making them very exciting candidates for high power laser mirrors. The films must be tested under vacuum in order to determine if incorporated water has any role to play in this behavior. None of the films show hysteresis after annealing procedures. Figure 1 shows data from a particularly strong NTE SiO_2 films while figure 2 shows average behavior for evaporated and sputtered NTE

SiO_2 films. Fig. 3 shows the coefficient of thermal expansion as a function of annealing temperature and the relationship (or lack thereof) between density and annealing temperature.

These graphs bring up some interesting points. First, the NTE of the evaporated films is robust up to the highest annealing temperatures, possibly indicating a stable microstructure. The density over this range stays fairly stable and is slightly lower than the density of sputtered films. Our previous results with zirconium tungstate showed that density played a critical role, changing by a factor of two between evaporated NTE and normal sputtered films. The lack of difference in density between the evaporated and sputtered SiO_2 films may indicate that previous theories about transverse vibrations causing NTE are incomplete. It seems probable that differences in deposition energetics are responsible in some way for the difference in behavior. We will be following this up aggressively in the coming year.

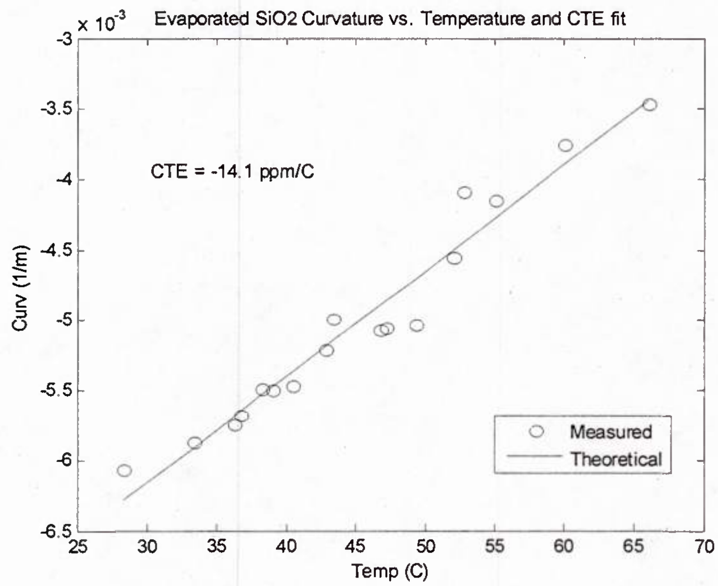

Figure 1 – Curvature vs. temperature for an evaporated SiO_2 film on silicon. This wafer was a film with particularly strong NTE. The measurements were performed under atmosphere using a laser interferometer.

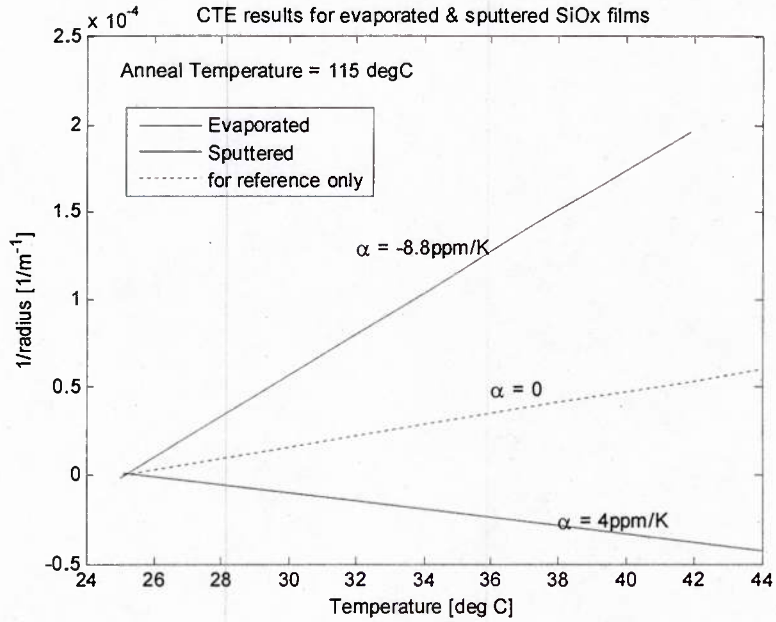

Figure 2 – Curvature vs. temperature averaged over a number of evaporated samples of SiO_2 films on silicon. Data extrapolated from a sputtered film (α = 4ppm/K) and a hypothetical zero expansion film are included for comparison. The measurements were performed under atmosphere using a laser interferometer.

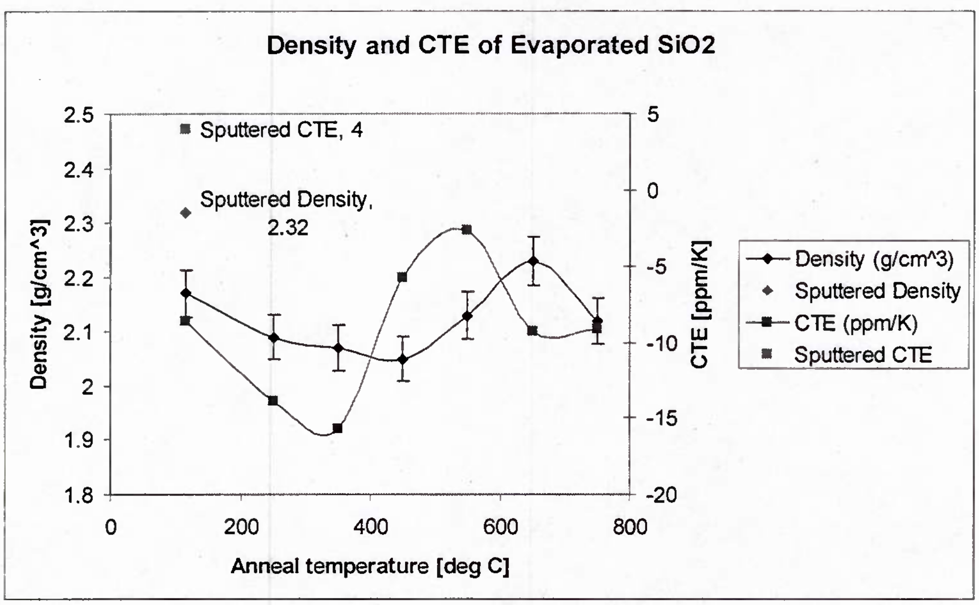

Figure 3 – Coefficient of thermal expansion (CTE) and density vs. anneal temperature for evaporated SiO_2 films. Points for the thermal expansion and density of a sputtered film are included for comparison. Note the erratic behavior of the CTE. The cause of this is under investigation.

5. Personnel Supported:

1. Joseph Talghader, PI (U Minnesota)
2. Phil Cohen, Professor, Thin Film Scientist (U Minnesota)
3. Nick Gabriel, graduate student (U Minnesota)
4. Mike Sutton, graduate student, advisory (U Minnesota)
5. Martin Soh, Fulbright Fellow (U Minnesota)

6. Publications

[1] M. S. Zamali and J. J. Talghader, "Stress mapping sensors for high power adaptive microoptics," *Applied Optics*, accepted and scheduled for publication in December 2005.

[2] M. S. Zamali and J. J. Talghader, "Stress mapping sensors for high power adaptive microoptics," *2005 IEEE Conference on Optical MEMS*, August 2005, pp. 187-188.

7. Interactions/Transitions

Northrop Grumman: We have recently begun discussions with John Starkovich of the Space Technology Division of Northrop Grumman about the use of negative thermal expansion materials as a coating material on polymer membranes. Dr. Starkovich sent us some Kapton material on which we will be depositing our NTE SiO_2 and ZrW_2O_8 films. These will be tested at Minnesota and NGC.

8. New discoveries, inventions or patent disclosures

Achieved negative thermal expansion in deposited thin film silicon dioxide. Verification in progress.

9. Awards/Honors

University of Minnesota, Multiple Patents Recognition, 2005

Conference Chair, 2006 IEEE Optical MEMS Conference